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# PROGRESS REPORT NORSAR PHASE 3

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Royal Norwegian Council for Scientific and Industrial Research

Prepared for:

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The report covers the period 1 April - 30 June 1973 which is characterized by improving, estimating and simulating the array detection capability. The operational performance of the field equipment has been satisfactory also in this report period, and preventive maintenance has been emphasized. Much programming effort has been invested in automating the array monitoring analysis. The 978 seismic events reported in June are mainly due to two earthquake swarms from Japan and Kamchatka. Evaluation studies of NORSAR detection performance gave the best results for events in Central Asia and (over)

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NORSAR Report No. 61

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2nd Quarter 1973

Prepared by

E.S. Husebye

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The NORSAR project has been sponsored by the United States of America under the overall direction of the Advanced Research Projects Agency and the technical management of the Electronic Systems Division, Air Force Systems Command, through Contract F19628-70-C-0283 with the Royal Norwegian Council for Scientific and Industrial Research.

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## SUMMARY

The report covers the period 1 April - 30 June 1973 which is characterized by improving, estimating and simulating the array detection capability. The operational performance of the field equipment has been satisfactory also in this reporting period, and preventive maintenance has been emphasized. Much programming effort has been invested in automating the array monitoring analysis. The 978 seismic events reported in June are mainly due to two earthquake swarms from Japan and Kamchatka. Evaluation studies of NORSAR detection performance gave the best results for events in Central Asia and adjacent regions when the 90% cumulative detectability values are in the range 3.6-3.8 NORSAR $m_b$ units. For events with $m_b$ above 4.0 NOAA reports the largest $m_b$ values, while NORSAR reports the largest for events with $m_b$ below 4.0

## 1. ADMINISTRATION AND ECONOMY

Representatives for Air Force Office of Scientific Research (AFOSR) Mr. W. Best, Captain J. Wilke and Lt. Col. Stevens (European Office of Aerospace Research) visited NORSAR 11-13 April. The purpose of the visit was contract negotiations for operation of the NORSAR array for the period 1 July 1973 - 30 June 1974.

Major R. Jedlicka (Electronic Systems Division - ESD) who had been attached to the NORSAR array as ESD Technical Project Officer (TPO) since 1 July 1968, left Norway as of 30 June 1973.

Expenditures in the period 1 April - 30 June 1973:

| | | | |
|---|---|---|---|
| 1. | Operation & Maintenance | | |
| 1.1 | Data Processing Center | $ 145,256 | |
| 1.2 | Field Installations | $ 28,666 | |
| 1.3 | Data Communications | $ 6,619 | $ 167,303 |
| 2. | Research & Development | | $ 15,979 |
| 3. | Administration & Support | | $ 24,361 |
| | TOTAL | | $ 207,643 |

## 2. ARRAY MONITORING AND FIELD MAINTENANCE

The normal corrective field maintenance tasks have generated a reasonable work load, thus implying stable and satisfactory performance of the array. A preventive field maintenance program is planned to be completed during the summer 1973 and 1974. So far, the work is ahead of schedule. The NORSAR Analog Station (NAS) has been inoperative most of May and June due partly to degraded transmission line quality between 05C and the NORSAR Data Processing Center (NDPC) and partly due to lack of spare parts for a faulty drum drive motor.

### NDPC Activity

The task of improving the analysis programs CHANEVSP and CHANEVLP has continued from the last reporting period. The main new features are options for reprints of previous analysis results and automatic monitoring of the seismic instrumentation both at NAS and the simulated subarray set-up at the NORSAR Maintenance Center (NMC) at Stange. Minor modifications with respect to parameter updatings and option for operator control of the execution of the above programs have also been accomplished.

Programs for statistical analysis and trend studies of critical array hardware parameters are in progress. Moreover, refined monitoring of array performance will be included in the above programs and possibly an option for predicting deteriorating quality of the data transmission channels.

NMC and NDPC Activity

Some of the investigations initiated in the previous reporting period and aimed at improving certain parts of the field equipment have so far given the following results:

- the present design of the protective lightning card in the data channel of an electronic unit in the Central Terminal Vault (CTV) implies a too small surge rating in the circuit. The resistors presently used will be replaced by wire-wound resistors with a larger thermal capacitance.

- the Short and Long Period Electronic Module (SLEM) discrete inputs are not well suited as line receivers. To enhance noise immunity a comparator with a suitable input filter will be used.

- a proposal for preventing electrolyte boiling in the CTV emergency torches has been presented to the manufacturer.

Field Maintenance

The preventive maintenance program this period consisted of:

- modifying the damping resistor of the LP instruments to bring the damping parameter within tolerance limits. This work was completed in the reporting period.

- maintenance of wood frames at the Well Head Vaults (WHV) and full checkout/replacement of RA-5 seismometer amplifiers. The subarrays 01A-07B have been checked and this work will continue for the C-ring throughout the summer and fall.

High frequency noise observed at 14C and previously assumed to be excessive instrument noise is in fact caused by extreme variations in the local seismic background noise.

To prevent a large number of cable breakages as experienced last year and caused mainly by local farmers, all land owners were informed of this problem. So far this year only two cables have been broken.

## 3. COMPUTER CENTER OPERATION AND DATA PROCESSING

### Programming Efforts

The main part of the programming effort in this period has been maintenance and improvements of the existing software systems. Much effort was invested in improving the Array Monitoring programs and in condensing the output from the Event Processor. Other programming tasks in the period are the following:

- To ease the program-machine-operator communication, a subroutine was developed to write a message to the operator and read a reply from the 1052 console typewriter on the IBM 360/40.

- A routine was made for searching the Detection Log Tape for Test/Calibrate records and printing the optionally wanted subfields of that record, within a specified time interval.

## Detection Processing

The Detection Processor (DP) was recording data on-line for approximately 97.8% of real time in April, 98.8% in May and 99.2% in June. Total down time was thus 31 hours in this period. Much of the down time was due to physical relocation of telephone lines and installation of the Terminal Interface Processor (TIP) for connection of NDPC to the ARPANET. For example, during two full days from 12 Apr 0900 to 14 Apr 1000 so few lines were in operation that no data could be satisfactorily processed by EP although DP was in operation most of the time.

The quality of the on-line data transmission from SDAC to NDPC (TAL) was as bad as in the previous reporting periods. The first available results after the installation of the TIP indicated that the change had not improved the quality of the transmitted seismic data.

## Event Processing

The number of reported events for the months April, May and June is given in Table 1.

| Month | Teleseismic | Core | Total |
|---|---|---|---|
| Apr 73 | 478 | 101 | 579 |
| May 73 | 389 | 90 | 479 |
| Jun 73 | 884 | 94 | 978 |

TABLE 1

The large number of events in June is due to two earthquake swarms from Kamchatka and Japan combined with especially low noise level. Such swarms always put some extra strain on the computer and analyst capacities, and some delays are unavoidable. Anyway, such large earthquake swarms are rare and can be handled.

The daily DP bulletin has been described and discussed in previous Progress Reports. External distribution started 18 May 1973, and the bulletin has been sent by Telex to seismological institutions in Bergen, Copenhagen, Hagfors and Helsinki. The response so far from the recipients has been very encouraging, and it seems that the bulletin has caused substantial changes in the daily seismogram reading procedures at some of the above institutions.

NORSAR Data Transmission via the ARPANET

The ARPANET Terminal Interface Processor (TIP) arrived at NORSAR 12 June, and installation started the same day led by Mr. N.M. Desourdy of Bolt, Beranek and Newman, Inc. No problems were encountered with the physical installation of the equipment; however, various malfunctions appeared when testing started. Hardware and/or software faults were found and fixed in TIP, Modem and teletype. For this purpose, local maintenance contractors were called in.

The voice grade line, earlier used for transmission of seismic data between NORSAR and Seismic Data Analysis Center (SDAC) at a rate of 2.4 Kbaud/sec caused considerable trouble when trials were made to operate at higher speeds. Various efforts were made during the 3 weeks following installation, with varying degrees of success. After a joint effort by the local telephone company NTA and ITT (4-5 July) the line quality seemed to improve sufficiently to allow more consistent testing, which is still continuing. In the meantime, the line to London University is being established, the tie-in of the London TIP (Terminal Interface Processor) being expected sometime in August.

In connection with the many formalities regarding the establishment and use of the ARPA network, a meeting was held with the Norwegian Telegraph Administration on 27 June, with participation of Dr. L.C. Roberts, ARPA, and Prof. P. Kirstein, London University. Meetings were also held with potential Norwegian users of the network.

## 4. RESEARCH AND DEVELOPMENT

Research and development efforts have been focused on problems relevant to the NORSAR event detection capability and system evaluation as in the previous period.

### Weighted Array Beamforming

The most important operation in array data processing is beamforming or so-called delay-and-sum processing in order to suppress the background noise. Physically this is equivalent to focusing the array on selected points in the seismically active regions. The underlying model is based on identical P-wave signals across the array, an assumption which is clearly not valid. Thus, using more realistic signal models would give significant gain in the signal-to-noise ratio (SNR) as discussed in the previous Quarterly Report. The work has been completed, and a report is being preapred by Christoffersson and Husebye (1973). A brief summation of the results is as follows. For NORSAR recorded teleseismic events, altogether 50 earthquakes in the Central Asia and Japan regions were analyzed, and a relative SNR gain of about 1.5-4.0 dB was obtained. The above gain was primarily due to only partially coherent signals across the array. The corresponding value for LASA, using earthquakes in the Aleutian Islands and the Central America regions, was 2.0-8.0 dB. Noteworthy, in the latter case the gain in SNR was primarily due to not well-equivalized subarray noise levels. For complex events, i.e., poor signal coherency and/or timing errors during beamforming, SNR gains up to 10 dB have been observed. Moreover, the new array signal processing technique is a promising tool for distinguishing between real P-wave and signal-like noise wavelets.

Bias Analysis of NORSAR and ISC Reported $m_b$ Magnitudes

Husebye et al (1973) have investigated the problem of a possible bias in NORSAR and ISC reported body wave magnitudes, and the results obtained are as follows. The signal energy losses observed during NORSAR P-wave beamforming do not in average affect its event magnitude estimates due to a skew, approximately lognormal, P-amplitude distribution across the array. A comparison between NORSAR-NOAA magnitude gave that the difference is largest at $m_b$~4.7 and then tapers off towards both small and large event magnitudes. For NOAA $m_b \leq 4.0$ NORSAR reports relatively large magnitude values. A multivariate analysis of ISC data for Japan and the Aleutian Islands gave a consistent and linear relationship between the ISC event magnitude and that predicted from subsets of 5-9 stations in the $m_b$~4.0-6.0 magnitude range investigated. In this respect the ISC reported magnitudes are considered unbiased. We also found that the magnitude observations may be approximated by a normal distribution. In many cases the so-called magnitude station correction term was not a constant but a function of event magnitude. This phenomenon is quantitatively explained as the combined effect of the seismic spectra scaling law (Aki, 1967, 1972) and the crust-upper mantle transfer function.

## Evaluation of NORSAR Event Detection and Location Performance

Since the NORSAR array became operational in Mar 1971, its performance in terms of event detectability and epicenter location accuracy has steadily improved due to software modifications and implementation of new data processing techniques. Based on one year of data, Apr 1972-Mar 1973, the routine event detectability of the NORSAR array in Norway has been investigated (Bungum & Husebye, 1973) in terms of 50% and 90% cumulative detectability thresholds which were derived from frequency-magnitude distributions. The best performance was observed for events in Central Asia and adjacent regions where the 90% cumulative detectability values are in the range 3.6-3.8 NORSAR $m_b$ units. For teleseismic events the value is 3.8. For events with $m_b$ above 4.0 NOAA reports the largest $m_b$ value, while NORSAR reports the largest for events with $m_b$ below 4.0. The accuracy of NORSAR-estimated epicenter solutions as compared to those of NOAA were also investigated. The best results were found for Japan and Central Asia, where the median location difference is 95 and 105 km, respectively. For teleseismic events, the value is 145 km. The biased errors in the location estimates are demonstrated to have been eliminated for most of the regions considered.

## NORSAR Event Detector Threshold Setting and the False Alarm Rate

At NORSAR a significant trend in seasonal noise level variations occur, and the same holds on a diurnal basis. For example, extreme cases with a variation in noise power up to 18 dB in the frequency band 2.0-3.0 Hz within a few hours have been observed at a large number of NORSAR short period sensor sites. This simply means that the array's event detection capability is lower during winter than summer time and also lower during the day than the night. In the latter case, there are roughly 20% more events detected during night time. Relevant data on the phenomena are presented and discussed in a recent report by Bungum and Ringdal (1973). Also, a similar study for long period noise is in progress.

An important but mostly ignored aspect of noise level fluctuations is that the statistical properties of the background noise change too. This explains why the number of times the Detection Processor is triggered by false messages varies considerably for a fixed signal-to-noise ratio. This problem was first considered by Lacoss (1972) who used a theoretical noise model for predicting the variability in the event detector false alarm rate. This work is continuing at NORSAR DPC, but here a pure empirical approach is preferred. The reason is that some of the basic assumptions underlying the noise model of Lacoss are not strictly valid, so large discrepancies are found between observed and predicted false alarm rates. This is not quite unexpected in view of the complex fluctuations of the noise spectra mentioned above. However, the so-called noise stability parameter, defined as the mean square of the noise divided by its variance, seems to adequately describe the variations in the false alarm rate as demonstrated in Fig. 1. In short,

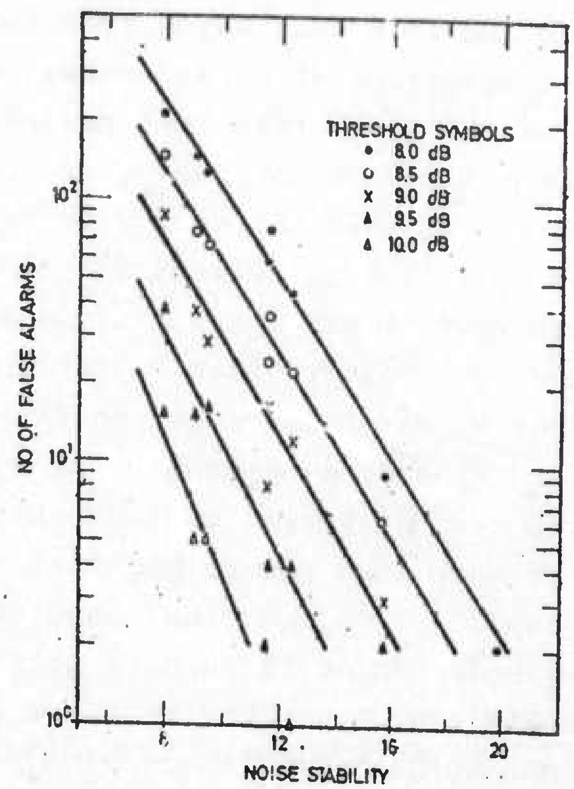


Fig. 1 False alarm rate versus noise stability for different event detector threshold values. Three different noise situations were analyzed, each corresponding to one hour of NORSAR on-line processing. For further variations of the noise structure 3 different bandpass filters were also used.

the results obtained so far point towards the possibility of having a floating NORSAR event acceptance threshold, which varies with the noise stability and is conditioned on a fixed false alarm rate.

Rayleigh Wave Interference

In addition to the seismic noise there is for long period waves an important limiting factor for the detectability in the fact that waves from two events are very often interfering with each other, maybe as much as 20% of the time. The long period coda from a large event may last for hours, and another complicating factor is that the energy is often scattered in azimuth through reflections and refractions at continental margins. A study is now in progress where the energy distribution in the coda for a number of carefully selected events is studied at 20 and 40 seconds period. The advantage of working at 40 seconds period is that the multipathing there is much less severe and that the coda fall off more rapidly. On the other hand, some events may have energy only around 20 seconds period. The results for NORSAR are comparable to those previously obtained for LASA by Capon and Evernden (1971), although it seems that NORSAR data give less variation in the way the coda around 40 second wave periods fall off with time.

5. MISCELLANEOUS

During the reporting period a number of scientists, whose names are listed below, have visited NORSAR Data Processing Center, Kjeller, for various research purposes.

Dr. J. Capon, Lincoln Lab, Mass. Inst. of Technology, Cambridge, Mass., U.S.A., from 16/5-11/6.

Dr. A. Christoffersson, Statistical Institute, Uppsala University, Uppsala, Sweden, from 12/6-30/6.

Dr. D. Doornbos, Utrecht University, Utrecht, The Netherlands, from 12/6-30/6.

Mr. J.M. Vermeulen, Utrecht University, Utrecht, The Netherlands, 18/6-30/6.

During the reporting period seven NORSAR scientists attended the Fourth Nordic Seminar on Detection Seismology in Helsinki 12-14 June.

Five NORSAR scientists participated in a Norwegian Geotravers meeting in Bergen 4-5 May.

One data tape was sold to E. Rygg, Seismological Observatory, Bergen, and 89 L-tapes were sent to SDAC.

<u>Reports completed in the period</u>

No. 57 Doornbos, D. and N.J. Vlaar, Regions of seismic wave scattering in the earth's mantle and precursors to PKP, April 1973

No. 58 Falch, K., Technical Description and Operation Instruction Ithaco Amplifier and Test Panel, April 1973.

No. 59 Husebye, E.S., Progress Report 1st Quarter 1973.

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Aki, K.: Scaling law of seismic spectrum, J. Geophys. Res., 72, 1217-1231 1967.

Aki, K.: Scaling law of earthquake source time function, Geophys. J.R. Astr. Soc., 31, 3-25, 1972.

Bungum, H., and E.S. Husebye: Analysis of the operational capabilities for detection and location of seismic events at NORSAR, In preparation.

Bungum, H., and F. Ringdal: Diurnal variation of seismic noise and its effect on detectability, In preparation.

Capon, J., and J.F. Evernden: Detection of Interfering Rayleigh waves at LASA, Bull. Seism. Soc. Am., 61, 807-849, 1971.

Christoffersson, A., and E.S. Husebye: Optimum signal estimation techniques in analysis of NORSAR and LASA array data. In preparation.

Husebye, E.S., A. Dahle and K.A. Berteussen: Bias analysis of NORSAR and ISC seismic event $m_b$ magnitudes. In preparation.

Lacoss, R.T.: Variation of false alarm rates at NORSAR, Semi-annual Technical Summary, Seismic Discrimination, MIT Lincoln Laboratory, Mass. Inst. of Tech., Cambridge, Mass., June 1972, 53-57.